International Academy of Astronautics

Cosmic Study 1.6

PROTECTED ANTIPODE CIRCLE ON LUNAR FARSIDE

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CHAPTER 1

PAC: PROTECTED ANTIPODE CIRCLE at the center of the Farside of the Moon for the benefit of all Humankind

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Summary

The international scientific community, and especially the IAA (International Academy of Astronautics), have long been discussing the need to keep the Farside of the Moon free from man-made RFI (Radio Frequency Interference).

Consider the center of the Farside and specifically crater Daedalus, located very close to the Antipode of the Earth, i.e. on the equator and at 180 deg in longitude. Daedalus is ideal to set up a future radio telescope (or phased array) to detect radio waves of all kinds that it is impossible to detect on Earth because of the ever-growing RFI.

In this Study we propose the creation of PAC (Protected Antipode Circle), a circular piece of land on the Farside centered at the Antipode and spanning an angle of 30 deg in longitude, latitude and all radial directions from the Antipode.

1 Defining PAC, the "Protected Antipode Circle"

The need to keep the Farside of the Moon free from man-made RFI (Radio Frequency Interference) has long been discussed by the international scientific community. In particular, in 2005 this author reported to the IAA (International Academy of Astronautics) the results of an IAA "Cosmic Study" that had been started back in 1994 by the late French radio astronomer Jean Heidmann (1920-2000) and had been completed by this author after Heidmann's death (see, for instance, [1] and [2]).

The center of the Farside, specifically crater Daedalus, is ideal to set up a future radio telescope (or phased array) to detect radio waves of all kinds that it is impossible to detect on Earth because of the ever-growing RFI.

Nobody, however, seems to have established a precise border for the circular region around the Antipode of the Earth (i.e. zero latitude and 180 deg longitude both East and West) that should be PROTECTED from wild human exploitation when several nations will have reached the capability of easy travel to the Moon.

In this paper we propose the creation of PAC, the Protected Antipode Circle. This is a large circular piece of land about 1820 km in diameter, centered around the Antipode on the Farside and spanning an angle of 30 deg in longitude, in latitude and in all radial directions from the Antipode, i.e. a total angle of 60 deg at the cone vertex right at the center of the Moon.

There are three sound scientific reasons for defining PAC this way:

1) PAC is the only area of the Farside that will never be reached by the radiation emitted by future human space bases located at the L4 and L5 Lagrangian points of the Earth-Moon system (the geometric proof of this fact is trivial);

2) PAC is the most shielded area of the Farside, with an expected attenuation of man-made RFI ranging from 15 to 100 dB or higher;
3) PAC does not overlap with other areas of interest to human activity except for a minor common area with the Aitken Basin, the southern depression supposed to have been created 3.8 billion years ago during the "big wham" between the Earth and the Moon.

Figure 1 shows a photo of the Farside of the Moon, the two parallels at plus and minus 30 deg drawn by solid red lines, and PAC, the Protected Antipode Circle, shown as the red, solid circle centered at the Antipode and tangent to the above two parallels at plus and minus 30 deg.

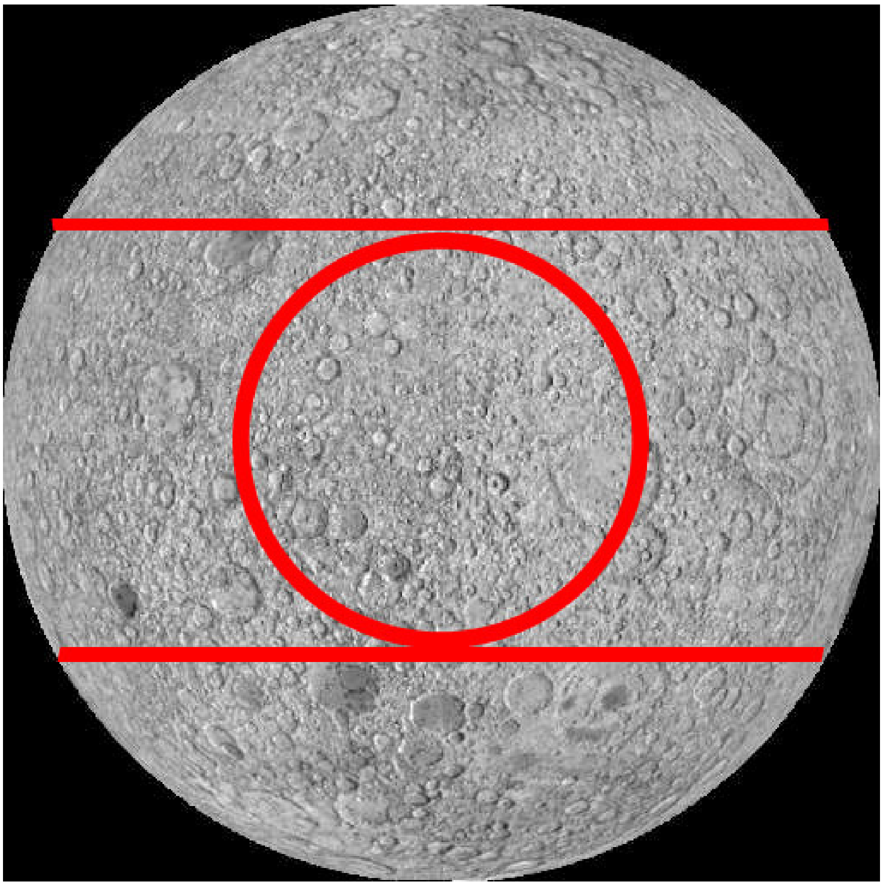

Figure 1 PAC, the Protected Antipode Circle, is the circular piece of land (1820 km in diameter along the Moon surface) that we propose to be reserved for scientific purposes only on the Farside of the Moon. At the center of PAC is the Antipode of the Earth (on the equator and at 180 deg in longitude) and, near to the Antipode, is crater Daedalus, an 80 km crater proposed by the author in 2005 as the best location for the future Lunar Farside Radio Lab. Inside Daedalus, the expected attenuation of the man-made RFI (Radio Frequency Interference) coming from the Earth is of the order of 100 dB or higher.

In view of these unique features, we propose PAC to be officially recognized by the United Nations as a **INTERNATIONAL PROTECTED AREA**, where no radio contamination by humans will possibly take place now and in the future.

This will be for the benefit of all Humankind.

2 Urgent Need for RFI-free radio astronomy

In order to detect radio signals of all kinds, as radio astronomers do, it is mandatory to firstly reject all RFI (Radio Frequency Interference). But RFI is produced in ever increasing amounts by the technological growth of civilization on Earth, and has now reached the point where large bands of the spectrum are blinded by legal or illegal transmitters of all kinds.

Since 1994, the late French radio astronomer Jean Heidmann pointed out that Radio astronomy from the surface of the Earth is doomed to die in a few decades if uncontrolled growth of RFI continues. Heidmann also made it clear, however, that advances in modern space technology could bring Radio astronomy to a new life, was Radio astronomy done from the Farside of the Moon, obviously shielded by the Moon spherical body from all RFI produced on Earth.

In view of the following developments in this paper, we present now a short review about the five Lagrangian points of the Earth-Moon system, shown in Figure 2.

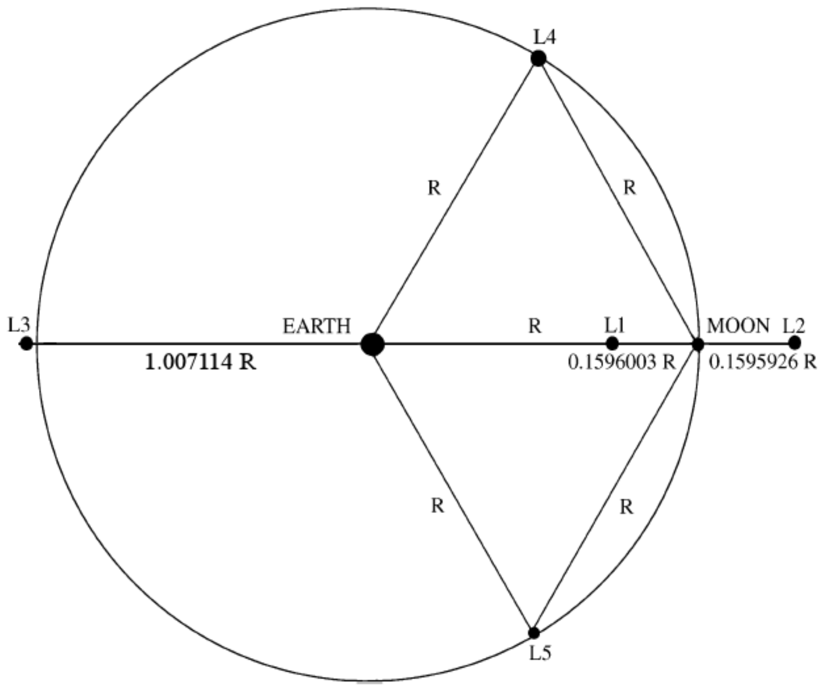

Figure 2 The five Earth-Moon Lagrangian Points (i.e. the points where the Earth and Moon gravitational pulls on a spacecraft cancel out!):

1) Let R denote the Earth-Moon distance that is 384,400 km. Then, the distance between the Moon and the Lagrangian point L1 equals 0.1596003*R, that is 61350 km. Consequently the Earth-to-L1 distance equals 0.8403997*R, that is 323050 km.
2) The distance between the Moon and the Lagrangian point L2 equals 0.1595926*R, that is 61347 km.
3) The distance between the Earth and the Lagrangian point L3 equals 1.007114*R, that is 387135 km.
4) The two "triangular" Lagrangian Points L4 and L5 are just at same distance R from Earth and Moon.

3 Terminal Longitude λ on the Moon Farside for Radio Waves emitted by Telecommunication Satellites in orbit around the Earth

In this section we prove an important mathematical formula, vital to select any RFI-free Moon Farside Base.

We want to compute the small angle α beyond the limb (the limb is the meridian having longitude 90° E on the Moon) where the radio waves coming from telecommunications satellites in circular orbit around the Earth still reach, i.e. they become tangent to the Moon's spherical body. The new angle $\lambda = \alpha + 90°$ we shall call "terminal longitude" of these radio waves. In practice, no radio wave from telecom satellites can hit the Moon surface at longitudes higher than this terminal longitude λ.

To find α (see Figure 3) we draw the straight line tangent to the Moon's sphere from G, the point tangent to the circular orbit having radius R. This straight line forms a right-angled triangle with the Earth-Moon axis, EM, with right angle at G. Next, consider the straight line parallel to the one above but from the Moon center M, intersecting the EG segment at a point P. Once again, the triangle EPM is right-angled in P, and it is similar to the previous triangle. So, the angle α is now equal to the EMP angle. The latter can be found, since:

1) The Earth-Moon distance $\overline{EM} = D_{Earth-Moon}$ is known and we assume its worst case (Moon at perigee): Earth-Moon distance equal to 356410 km.
2) The $\overline{EP}$ segment equals the $\overline{EG} = R$ segment minus the Moon radius, R_{Moon}.
3) Using Pythagoras' theorem one finds $\overline{PM} = \sqrt{\left(\overline{EM}\right)^2 - \left(\overline{EP}\right)^2}$.
4) The tangent of the requested angle α is then given by $\tan \alpha = \dfrac{\overline{EP}}{\overline{PM}} = \dfrac{\overline{EP}}{\sqrt{\left(\overline{EM}\right)^2 - \left(\overline{EP}\right)^2}}$.

Inverting the last equation and making the substitutions described at the points 1), 2) and 4), one gets the terminal longitude λ of radio waves on the Moon Farside (between 90° E and 180° E) emitted by a telecom satellite circling around the Earth at a distance R:

$$\lambda = \operatorname{atan}\left(\frac{R - R_{Moon}}{\sqrt{D_{Earth-Moon}^2 - \left(R - R_{Moon}\right)^2}}\right) + \frac{\pi}{2}.$$

Here the independent variable R can range only between 0 and the maximum value that does not make the above radical become negative, that is $0 \le R \le D_{Earth-Moon} + R_{Moon}$. The equation above for λ shows that the $\lambda(R)$ curve becomes vertical for $R \to \left(D_{Earth-Moon} + R_{Moon}\right)$ and $\lambda = 180°$

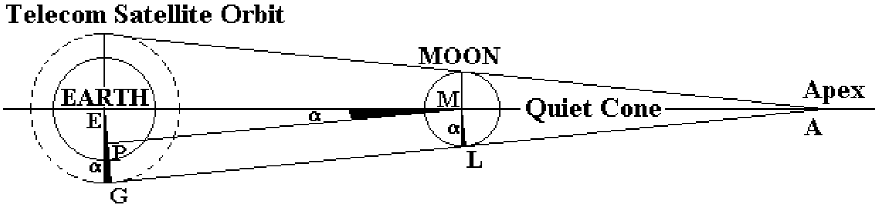

Figure 3 The simple geometry defining the "Terminal Longitude, λ" on the Farside of the Moon, where radio waves emitted by telecom satellites circling the Earth at a radius R are grazing the Moon surface.

4 Selecting Crater Daedalus near the Farside Center

This author claims that the time will come when commercial wars among the big industrial trusts running the telecommunications business by satellites will lead them to grab more and more space around the Earth, pushing their satellites into orbits with apogee much higher than the geostationary one. *A "safe" crater must be selected East along the Moon equator. How much further East?* The answer if given by the diagram in Figure 4, based on the above equation for λ.

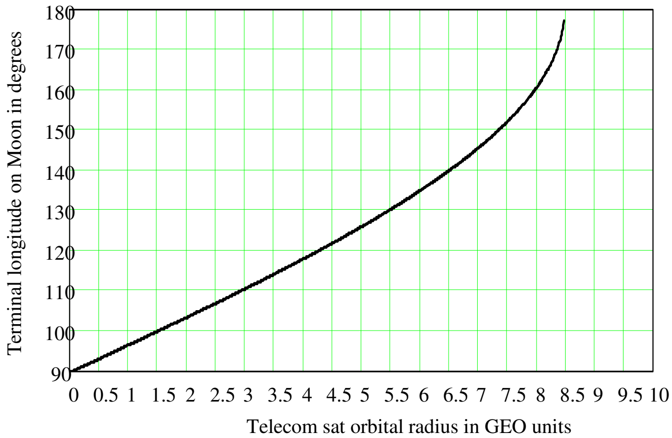

Figure 4 Terminal longitude λ (vertical axis) on the Moon Farside versus the telecom satellites orbital radius R around the Earth (horizontal axis) expressed in units of the Earth's geostationary radius (42241.096 km).

The vertical trait predicted by our equation for λ shows up in Figure 4 as the "upgoing right branch". This shows that, if we only keep the equation for λ into account, the maximum distance from the Earth's center for these telecom satellites is about 8.479 times the geostationary radius, corresponding to a circular orbital radius of 358148 km. Was a telecom satellite put in such a circular orbit around the Earth, its radio waves would flood Moon longitudes as high as about ~175° or more. However we did not consider the Lagrangian points yet!

So, it will never be possible to put a satellite into a circular orbit around the Earth at a distance of 358148 km, simply because this distance already lies beyond the distance of the Lagrangian point L1 nearest to the Earth, that is located at 323050 km (Lagrangian points are, by definition, the points of zero orbital velocity in the two-body problem!).

So we are now led to wonder: what is the Moon Farside terminal longitude corresponding to the distance of the nearest Lagrangian point, L1 ? The answer is given by the above equation for λ upon replacing R = 323050 km, and the result is $\lambda = 154.359°$. In words, this means the following: *the Moon Farside Sector in between 154.359 E and 154.359 W will never be blinded by RFI coming from satellites orbiting the Earth alone.*

In other words, the *limit* of the blinded longitude as a function of the satellite's orbital radius around the Earth is 180° (E and W longitudes just coincide at this meridian, corresponding to the "change-of-date line" on Earth). But this is the *Antipode* to Earth on the Moon surface that is the point exactly opposite to the Earth direction on the other side of the Moon. And our theorem simply proves that the antipode is the most shielded point on the Moon surface from radio waves coming from the Earth. An intuitive and obvious result, really.

So, where are we going to locate our SETI Farside Moon base? Just take a map of the Moon Farside and look. One notices that the antipode's region (at the crossing of the central meridian and of the top parallel in the figure) is too a rugged region to establish a Moon base. Just about 5° South along the 180° meridian, however, one finds a large crater about 80 km in diameter, just like Saha. This crater is called Daedalus. So, *this author proposes to establish the first RFI-free base on the Moon just inside crater Daedalus, the most shielded crater of all on the Moon from Earth-made radio pollution!*

Figure 5 AS11-44-6609 (July 1969) - An oblique of the Crater Daedalus on the Lunar Farside as seen from the Apollo 11 spacecraft in lunar orbit. The view looks southwest. Daedalus (formerly referred to as I.A.U. Crater No. 308) is located at 179 degrees east longitude and 5.5 degrees south latitude. Daedalus has a diameter of about 50 statute miles (~ 80 km). This is a typical scene showing the rugged terrain on the Farside of the Moon, downloaded from the web site:
http://spaceflight.nasa.gov/gallery/images/apollo/apollo11/html/as11_44_6609.html

5 Our Vision of the Moon Farside for RFI-free Science

Let us replace the simpler value of λ=154.359° with the simpler value of λ=150°. This matches perfectly with the need for having the borders of the Pristine Sector making angles orthogonal to the directions of L4 and L5. The result is this author's vision of the Farside of the Moon, shown in Figure 6.
Figure 6 shows a diagram of the Moon as seen from above its North Pole with the different "colonization regimes" proposed by this author. One sees that:

1) The near side of the Moon is left totally free to activities of all kinds: scientific, commercial and industrial.
2) The Farside of the Moon is divided into three thirds, namely three sectors covering 60° in longitude each, out of which:
   a) The Eastern Sector, in between 90° E and 150° E, can be used for installation of radio devices, but only under the control of the International Telecommunications Union (ITU-regime).

b) The Central Sector, in between 150° E and 150° W, must be kept totally free from human exploitation, namely it is kept in its "pristine" radio environment totally free from man-made RFI. This Sector is where crater Daedalus is, a ~ 100 km crater located in between 177° E and 179° W and around 5° of latitude South. At the moment, this author is not aware of how high is the circular rim surrounding Daedalus.

c) The Western Sector, in between 90° W and 150° W, can be used for installation of radio devices, but only under the control of the International Telecommunications Union (ITU-regime). Also:

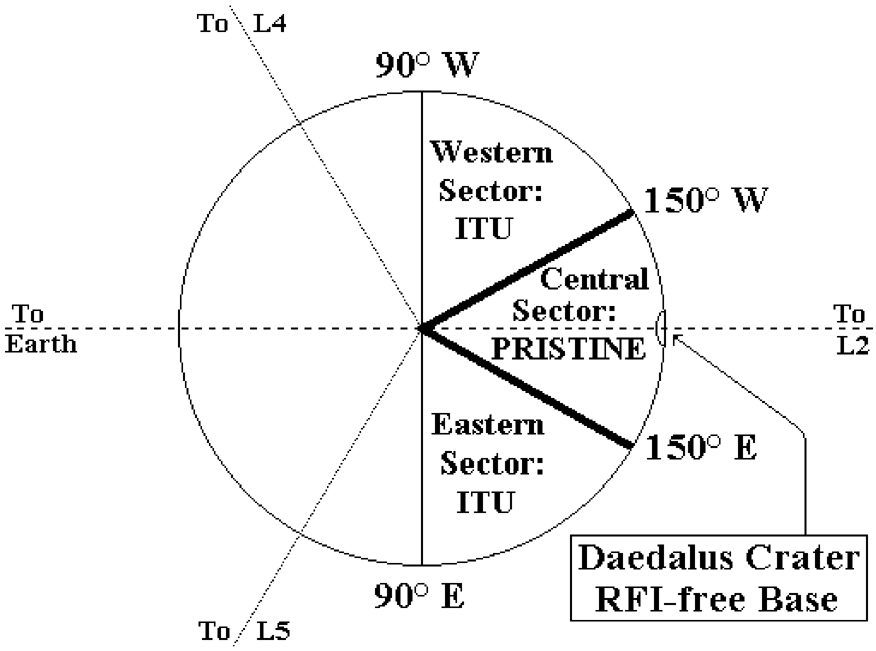

Figure 6. Our vision of the Moon Farside with the Daedalus Crater Base for RFI-free Radio astronomy, Bioastronomy and SETI science. Future International Space Stations (ISS) might be located at both the L4 and L5 Earth-Moon Points in the decades to come. Only Point L2 will have to be kept free at all times.

1) The Eastern Sector is exactly opposite to the direction of the Lagrangian point L4, and so the body of the Moon completely shields the Eastern Sector from RFI produced at L4. Thus, L4 is fully "colonizable".
2) The Western Sector is exactly opposite to the direction of the Lagrangian point L5, and so the body of the Moon completely shields the Western Sector from RFI produced at L5. Thus, L5 is fully "colonizable" in this author's vision. In other words, this author's vision achieves the *full bilateral symmetry* around the plane passing through the Earth-Moon axis and orthogonal to the Moon's orbital plane.
3) Of course, L2 may not be utilized at all, since it faces crater Daedalus just at the latter's zenith. Any RFI-producing device located at L2 would flood the whole of the Farside, and must be ruled out. L2, however, is the only Lagrangian point to be kept free, out of the five located in the Earth-Moon system. Finally, L2 is not directly visible from the Earth since shielded by the Moon's body, what calls for "leaving L2 alone"!

6 The Further Two Lagrangian Points L1 and L2 of the Sun-Earth System: their "polluting" action on the Farside of the Moon

There still is an unavoidable drawback, though.
This is coming from the *further two Lagrangian points L1 and L2 of the Sun-Earth system*, located along the Sun-Earth axis and outside the sphere of influence of the Earth that has a radius of about 924646 km around the Earth. Precisely, the Sun-Earth L1 point is located at a distance of 1496557.035 km from the Earth towards the Sun, and the L2 point at the (virtually identical) distance of 1496557.034 km from the Earth in the direction away from the Sun, that is toward the outer solar system. These two points have the "nice" property of moving around the Sun just with the same angular velocity as the Earth does, while keeping also at the same distance from the Earth at all times. Thus, they are *ideal places for scientific satellites*.

Actually, the Sun-Earth L1 Point has already been in use for scientific satellite location since the NASA ISEE III spacecraft was launched on 12 August 1978 and reached the Sun-Earth L1 region in about a month. On December 2, 1995, the ESA-NASA "Soho" spacecraft for the exploration of the Solar Corona was launched. On February 14, 1996, Soho was inserted into a halo orbit around the Sun-Earth L1 point, where it is still librating now (2007).

As for the Sun-Earth L2 point, there are plans to let the NASA's SIM (Space Interferometry Mission) satellite be placed there, as will be ESA's GAIA astrometric satellite as well.

So, all these satellites do "POLLUTE" the otherwise RFI-free Farside of the Moon when the Farside is facing them. Unfortunately, the Moon Farside is facing the Sun-Earth L1 point for half of the Moon's synodic period, about 14.75 days, and it is facing the Sun-Earth L2 point for the next 14.75 days. Really all the time!

This radio pullution of the Moon Farside by scientific satellites located at the Lagrangian Points L1 and L2 of the Sun-Earth system is, unfortunately, UNAVOIDABLE. We can only hope that telecom satellites will never be put there. As for the scientific satellites already there or on the way, the radio frequencies they use are well known and usually narrow-band. This should help the Fourier transform of the future spectrum analyzers to be located on the Moon Farside to get rid of these transmissions completely.

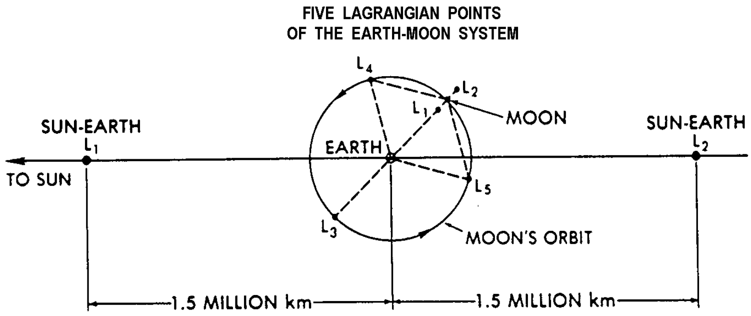

Figure 7 (Courtesy of Dr. Robert "Bob" Farquar, Johns Hopkins University Applied Physics Laboratory, Laurel, MD, USA). In addition to the five Lagrangian Points of the Earth-Moon system (already described in Figure 1) the next two closest Lagrangian Points to the Earth are the Lagrangian Points L1 and L2 of the Sun-Earth system. These are located along the Sun-Earth axis at the distances of about 1.5 million kilometers from the Earth toward the Sun (L1) and outward (L2). Unfortunately, spacecrafts located in the neighbourhood of these L1 and L2 Sun-Earth Points do send electromagnetic waves to the Farside of the Moon. Examples are the ISEE-III and Soho spacecrafts, already orbiting around L1, and more spacecrafts will do so in the future around both L1 and L2.

7 Attenuation of man-made RFI on the Moon Farside

In a recent paper presented by this author at the International Astronautical Congress held in Valencia in October 2006, his co-worker Salvo Pluchino succeeded in computing the RFI attenuation on the Farside of the Moon [3]. A basic result proven there are the RFI attenuation values shown in Table 1 hereafter.

Frequency or radio waves	*f* = 100 kHz	*f* = 100 MHz	*f* = 100 GHz
Source in GEO	- 42.62 dB	- 72.62 dB	- 102.62 dB
Source in an orbit passing through the L1 point	- 30.32 dB	- 60.32 dB	- 90.32 dB
Source still at L4 or L5 Lagrangian points	- 29.15 dB	- 59.15 dB	- 89.15 dB

Table 1 Radio waves attenuation in the lunar equatorial plane and at lunar longitude λ = 180° (i.e. near the Daedalus crater) for radio sources emitting at 100 kHz, 100 MHz and 100 GHz, respectively. All attenuation values are in dB.

Perhaps even more important than the "generic" frequency values listed in Table 1 are the following precise line frequencies high scientific importance again taken from the paper [3]. In practice, these are the attenuations of man-made RFI to be expected at crater Daedalus and within the PAC. It should also be stated that these are the attenuation values assuming that the Moon is *not* surrounded by a very thin ionosphere. Since a very tiny Lunar Ionosphere might possibly exist, however, the values below might be slightly incorrect.

Origin of radio waves	Radio frequency *f*	Source in GEO	Source in orbit at L1 distance	Source still at L4 or L5
ELF	0.003 MHz	-27.39 dB	-15.57 dB	-14.61 dB
VLF	0.030 MHz	-37.39 dB	-25.10 dB	-23.94 dB
Jupiter's storm	20 MHz	-65.63 dB	-53.33 dB	-52.16 dB
Deuterium	327.384 MHz	-77.77 dB	-65.48 dB	-64.30 dB
Hydrogen	1420.406 MHz	-84.14 dB	-71.85 dB	-70.68 dB
Hydroxyl radical	1612.231 MHz	-84.69 dB	-72.40 dB	-71.23 dB
Formaldehyde	4829.660 MHz	-89.46 dB	-77.17 dB	-75.99 dB
Methanol	6668.518 MHz	-90.86 dB	-78.56 -dB	-77.39 dB
Water vapor	22.235 GHz	-96.09 dB	-83.79 dB	-82.62 dB
Silicon monoxide	42.519 GHz	-98.90 dB	-86.61 dB	-85.44 dB
Carbon monoxide	109.782 GHz	-103.02 dB	-90.73 dB	-89.56 dB
Water vapor	183.310 GHz	-105.25 dB	-92.95 dB	-91.78 dB

Table 2 Attenuation in the lunar equatorial plane and at lunar longitude at λ = 180° (near the Daedalus crater) for radio waves having some of the most important frequencies used by radioastronomers to explore the universe.

Conclusions

The goal of this paper was to make the readers sensitive to the importance of protecting the Central Farside of the Moon from any future wild, anti-scientific exploitation.

In particular, we gave sound scientific reasons why the PAC, Protected Antipode Circle, should be declared an international land under the Protection of the United Nations, or, in absence of that institution, by direct agreement among the space-faring nations.

The Farside of the Moon is a unique place for us in the whole universe: it is close to the Earth, but protected from the radio garbage that we ourselves are creating in ever increasing amount that is making our radio telescopes blinder and blinder.

The Farside cannot be left to the realtor's speculations!

And this is an *urgent* matter!

Some international agreement must be taken for the benefit of all Humankind.

Acknowledgments

The author would like to thank the International Academy of Astronautics (IAA) for allowing him to serve as Coordinator of the "Lunar Farside Radio Lab" IAA Cosmic Study in the years 2000-2005.

Interest in the international role that the United Nations might play in the creation of the PAC also came from several members of the International Institute of Space Law (IISL), in particular Prof. Vladimir Kopal, Chair of the IAA "Scientific-Legal Liaison Committee". Hopefully, these and other far-sighted minds will unite their efforts to save the Farside of the Moon from new man-made RFI pollution right over there!

Finally, the support of the author's co-workers Salvo Pluchino and Nicolò Antonietti is gratefully acknowledged in the study of the mathematical problems to quantify the RFI on the Moon Farside.

References

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[2] C. Maccone, "Moon Farside Radio Lab", Acta Astronautica, Vol. 56, 2005, pp. 629-639.

[3] S. Pluchino, N. Antonietti and C. Maccone, "Protecting the Moon Farside Radiotelescopes from RFI produced at future Lagrangian-Points Space Stations", paper IAC-06-D4.1.01 presented at the International Astronautical Congress held in Valencia (Spain), October 2-6, 2006.

CHAPTER 2

MEMO ON LEGAL ASPECTS OF PROTECTING THE FARSIDE OF THE MOON AND PRESERVING IT FOR SCIENTIFIC ACTIVITIES

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Summary

This Memo sets out in brief terms:

1) The current legal status of the Moon, including its Farside;
2) The legal consequences and parameters following from that legal status for protecting the Farside against activities which may or would interfere with possible scientific activities, notably astronomic activities, there; and
3) What measures could be undertaken to establish a certain level of protection of such scientific activities.

1 The current legal status of the Moon, including its Farside

The key document providing for the legal status of the Moon, and all other existing international legal aspects of the current issue, is the 1967 Outer Space Treaty (Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and Other Celestial Bodies), in view of the fact that the 1979 Moon Agreement (Agreement Governing the Activities of States on the Moon and Other Celestial Bodies) has been poorly ratified, and not by any of the major spacefaring countries.

The Outer Space Treaty in Article II provides that “Outer space, including the Moon and other celestial bodies, is not subject to national appropriation by claim of sovereignty, by means of use or occupation, or by any other means.” This determines the status of the Moon as a ‘global commons’, a *terra communis* which is not and can never become part of one state or another, and at the same time is available for proper use to all states without discrimination.

This is reinforced by Article I, providing *inter alia* that “Outer space, including the Moon and other celestial bodies, shall be free for exploration and use by all States without discrimination of any kind, on a basis of equality and in accordance with international law, and there shall be free access to all areas of celestial bodies”. In addition, Article XII provides that “All stations, installations, equipment and space vehicles on the Moon and other celestial bodies shall be open to representatives of other States Parties to the Treaty on a basis of reciprocity. Such representatives shall give reasonable advance notice of a projected visit, in order that appropriate consultations may be held and that maximum precautions may be taken to assure safety and to avoid interference with normal operations in the facility to be visited."

Any legal regime providing limitations to that fundamental freedom of exploration and use of outer space would have to be developed on an international level, by the community of states jointly. The Outer Space Treaty itself provides the first and most general of such a further legal regime, as it for example requires states to accept international responsibility (Article VI) and liability (Article VII) for relevant sets of space activities, to cooperate internationally and in accordance with general international law (Articles III, IX, X, XI), to inform and consult in case their space activities may threaten to seriously interfere with other state's activities (Articles IX, XI), to abide by the treaty's norms also if cooperating in the context of intergovernmental organizations (Article XIII) and not to orbit or station weapons of mass destruction in outer space (Article IV).

Further rules are provided by a set of UN sponsored international treaties which elaborated the Outer Space Treaty, notably the 1968 Rescue Agreement (Agreement on the Rescue of Astronauts, the Return of Astronauts and the Return of Objects Launched into Outer Space), the 1972 Liability Convention (Convention on International Liability for Damage Caused by Space Objects) and the 1975 Registration Convention (Convention for the Establishment of a European Space Agency). These agreements however are of no direct relevance for the current issue, and therefore need not be further discussed presently.

In short: the legal status of the Moon is that of a 'global commons', where the basic rule is freedom of exploration and use as limited only by further internationally agreed limitations on such freedom, such as imposed by the Outer Space Treaty itself. This analysis comprehensively also applies to the Farside of the Moon.

2 The legal consequences and parameters following from the legal status of the Moon

The primary consequence of the above summary analysis of the legal status of the Moon for protecting the Farside against activities which may or would interfere with possible scientific activities, notably astronomic activities, on that Farside is that any further legal measures in support of such aims would have to be agreed on the international level. This would, for example, concern a limitation of access to areas on the Moon, such as on the Farside, in order to prevent intrusion of and interference with scientific activities undertaken there.

The aforementioned clause of Article XII *only* provides some limitations to the right of other states to visit a station on the Moon without any previous warning, *not* to visit that station as such or even refrain from undertaking their own activities in the vicinity, unless it directly interferes in a serious manner with the activities of such a station. Even then, currently Article IX essentially only requires such states to consult in good faith, not *per se* to desist from such activities in case it can be proven that serious harm might be caused to the station's activities.

Generally speaking, the abovementioned Liability Convention is supposed to deal with cases where such harm would actually occur, although the scope of application of that regime in the current context may be considerably limited by the way relevant concepts such as 'space objects' and 'damage' compensable under the Convention are defined, and the absence of direct liability for private operators under it.

At the same time, further to the above analysis, specifically with reference to scientific exploration and use, it is to be noted on the one hand that Article I of the Outer Space Treaty also states that "The exploration and use of outer space, including the Moon and other celestial bodies, shall be carried out for the benefit and in the interests of all countries, irrespective of their degree of economic or scientific development, and shall be the province of all mankind", and that "There shall be freedom of scientific investigation in outer space, including the Moon and other celestial bodies, and States shall facilitate and encourage international cooperation in such investigation."

In other words: scientific exploration represents a major goal for all space activities, and in the abstract no space activities should be allowed to ignore or fundamentally interfere with the freedom of states to undertake such activities, including scientific activities conducted on the Farside of the Moon. This is also the consequence of obligations of international cooperation, non-harmful interference with other states' activities and furthering the benefits of all countries, found in the various Articles of the Outer Space Treaty referred to before.

In short: the fundamental consequence of the status of the Moon is that on the one hand scientific activities on the Farside of the Moon are allowed, even strongly supported in the abstract as being manifestations of the major aims of the Outer Space Treaty, but that on the other hand the freedom of other states to undertake space activities in *their* exercise of the free right of use and exploration, thus possibly interfering with scientific activities on the Farside of the Moon, cannot be substantially obstructed without further ado.

3 Measures to be undertaken to protect scientific activities on the Farside of Moon

The approach with the largest chance of success to achieve a certain level of protection of such scientific activities on the Farside of the Moon is pointed out by the Moon Agreement. Whilst the Agreement strictly speaking is of little binding value as a treaty, in view of the aforementioned widespread refusal of the spacefaring nations to ratify it, the overriding reason for that refusal was the determination, by means of Article 11, that the Moon was to be considered the 'common heritage of mankind', with the likely results that this would lead to in terms of mandatory sharing of (the benefits of) exploited resources as well as of the technology used for such exploitation.

All other clauses of the Moon Agreement generally speaking met with little resistance. Even the United States, the most vocal in refusing to accept such consequences to result from the invocation of the common heritage of mankind-priniple, greatly contributed to the drafting of the Agreement and most of its clauses, before a new political climate caused them to shirk back from signing and ratifying the Agreement for reasons of Article 11's perceived potential impact.

Thus, the clause of Article 7(3) providing that "States Parties shall report to other States Parties and to the Secretary-General concerning areas of the Moon having special scientific interest in order that, without prejudice to the rights of other States Parties, consideration may be given to the designation of such areas as international scientific preserves for which special protective arrangements are to be agreed upon in consultation with the competent bodies of the United Nations" never constituted a bone of contention. As a matter of fact, especially US authors have claimed several times that the landing sides of the successful Apollo missions should be preserved in similar fashion, and even such international law-ignoring enterprises as Lunar Embassy, purportedly selling plots on the Moon, officially declared that those places were excluded from its sales activities.

The fact that only a few, largely non-spacefaring states would be formally entitled to invoke this clause and to do so moreover only against a few others, simply means that the Moon Agreement on this issue should not be used as a binding legal instrument, but as an analogy for what should be argued to be a necessary development.

Also, on earth, in the context of Antarctica (the continent closest to presenting analogies for scientific activities in terms of living and working environment and difficulties related to both), such an option has been created, and even made use of: the whole continent is now formally labeled a ‘Scientific Reserve’, with due consequences for the rights to undertake scientific activities there without undue interference by commercial or other non-scientific activities.

In other words: in order to establish protection for scientific activities on the Farside of the Moon, (1) certain states should be engaged in reporting to the international community, notably COPUOS, that particular areas on the Farside of the Moon are of “special scientific interest”, (2) propose to designate them “international scientific preserves” in analogy to the Moon Agreement’s proposed regime or “scientific reserves” in analogy to Antarctica, and (3) discuss in detail what specific legal consequences such a designation should carry, in order to achieve the desired level of protection. Notably, finally, (4) the consequences of such an international regime should be mandatorily flowed down, as relevant, to private operators by means of national law and national licensing systems.

Further supporting arguments could be found in the various clauses of the Outer Space Treaty referred to, stressing the importance of scientific exploration in the context of space activities, the respect such exploration should enjoy in relation to other space activities, and the need for international cooperation and agreement to establish clear rules to implement these general principles in the specific context of the Farside of the Moon.

4 Concluding remarks

The general approach sketched would offer sufficient opportunities to arrive at protection measures for scientific activities on the Farside of the Moon, notably through the establishment of ‘international scientific preserves’ or ‘scientific reserves’. The present Memo cannot go into the various details of the existing legal framework for scientific activities and the possible establishment of such a measure of protection, including also the various ramifications on the level of domestic law and regulation, but further analysis would largely and broadly corroborate that approach, provide further details and indications on how to proceed as well as what the key issues to be included in such a regime of ‘international scientific preserves’ or ‘scientific reserves’ would turn out to be.

At this point, the main issue is of course to generate sufficient interest with a number of key states to be able to provide such proposals with sufficient weight for a reasonable chance of success.

Lincoln, Nebraska, January 2010

Frans von der Dunk

Into the Dark Ages: A Lunar-Orbiting, Low Frequency Antenna to Measure the Global Signatures of the First Collapsing Structures in the Early Universe

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The 21-cm hyperfine transition of hydrogen holds great promise for tracking the evolution of the Universe and constraining the birth of the first stars and black holes. We describe a single antenna experiment in lunar orbit that would be the first to observe the Universe during and after the "Dark Ages" when the Universe was < 1 billion yrs old. The all-sky hydrogen signal has predicted features at frequencies between 25 and 100 MHz that are characteristic of the expansion of the Universe and the ignition of stars and/or black holes. However, this portion of the radio spectrum is heavily contaminated by civil and military transmitters much stronger than the hydrogen signal. A single dipole antenna in lunar orbit, carried into the radio shielded zone above the farside, operating at 25–100 MHz has much potential for cosmological measurements. A stable broadband spectrometer with carefully controlled noise properties on the spacecraft bus will be required to carry out high dynamic range observations. Also required will be robust algorithms for removal of the Galactic foregrounds, which are being developed by ground-based experiments operating at higher frequencies. These data will be the first to produce measurements of the Universe's reionization about 13 billion yrs ago.

Probing the cosmic dark ages with a low-frequency radio antenna in lunar orbit

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A low-frequency radio antenna on the far side of the Moon, or in lunar orbit, may allow detection of redshifted 21-cm absorption and emission from the cosmic dark ages and the epoch of reionization, and lead to constraints on cosmology and on the first sources of radiation in the Universe. I will argue why it is attractive, and probably necessary, to place the antenna on or near the Moon rather than on the Earth. One challenge facing such an experiment is the intense foregrounds originating from our Galaxy and from extragalactic sources, which place very stringent requirements on the capabilities of the instrument and the data analysis. I will show the results of our program to model the observations of a lunar-orbiting low-frequency dipole experiment and to extract a simulated 21-cm signal from them. I will also discuss the possibility of using the Moon itself as a calibration source. The concept of this experiment is similar to that of a higher-frequency experiment, EDGES, being conducted from the Earth. I will show how the extension to low frequencies enabled by an experiment in lunar orbit makes the extraction of a signal more tractable, and may greatly enhance the scientific potential of such an experiment.

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From the Lunar Ionosphere to the First Stars

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The modern Universe is nearly fully ionized—-even in our own solar system, most of the mass is in the Sun, which is a ball of ionized hydrogen. However, for about 1 billion years after the Big Bang, the temperature was cool enough that hydrogen was neutral. One of the key challenges in modern astrophysics is to understand the timing and cause(s) of this transition from a neutral to ionized state, known as the Epoch of Reionization.

The NLSI LUNAR team mission includes using the Moon as a platform for studying the Universe. We will motivate how a Lunar Radio Array, emplaced on the far side of the Moon, would be an impressive instrument for studying the first stars, the Epoch of Reionization, and even the time before the first stars, known as the cosmic Dark Ages. Before the LRA, there will likely be a series of scientific and technological pathfinders. We will outline a roadmap, starting from small instrument packages, conducting both science from the Moon and science of the Moon, to the full LRA.

The LUNAR consortium is funded by the NASA Lunar Science Institute (via Cooperative Agreement NNA09DB30A) to investigate concepts for astrophysical observatories on the Moon.

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IAA proposes UN COPUOS to protect the central Moon farside against man-made radio pollution

Long-term thinking means planning for the consequences of things that are beyond our current capacity. What happens on the farside of the Moon is a case in point. Getting humans back to the Moon is going to happen sooner or later, and one day we will have bases there, as well as a human or robotic presence at the L4 and L5 Lagrangian points of the Earth-Moon system. That means an ever growing blanket of electromagnetic radiation from our various activities. At the same time, we want to protect the farside, which is ideal for future radio telescope or phased array detectors. What to do?

Italian IAA Academician and physicist Claudio Maccone has brought this issue to Vienna, speaking before the United Nations Committee on the Peaceful Uses of Outer Space.

Maccone is proposing a radio-quiet zone on the farside that will guarantee radio astronomy and SETI a defined area in which human radio interference is impossible. It's an idea with a pedigree, going back to 1994, when the French radio astronomer Jean Heidmann first proposed a SETI observatory in the farside Saha Crater with a link to the nearside Mare Smythii plain and thence to Earth.

An IAA study committee grew out of this and a series of discussions since, with Heidmann's death in 2000 being followed by Maccone's taking over the project. As Maccone told the UN committee meeting, radio interference becomes a serious threat when we consider the uses to which the Lagrangian points could be put. The Earth/Moon system has five such points, as shown in the diagram. Potential space operations could take place at all of these except, let's hope, L2, which as you can see in the diagram is located so that a base there would flood the farside with interference. The first principle is then clear: Leave the L2 point alone.

As for the others, the diagram makes it equally clear that inteference from L4 and L5 would reach large parts of the farside, but Maccone's figures show that a protected area is still possible. He is proposing a Protected Antipode Circle, defined as a circular piece of land 1820 kilometers in diameter, centered around the antipode on the farside and spanning an angle of 30 degrees in longitude, in latitude and in all radial directions from the antipode. The rationale, as presented by Maccone in a 2008 paper:

1) PAC is the only area of the Farside that will never be reached by the radiation emitted by future human space bases located at the L4 and L5 Lagrangian points of the Earth-Moon system (the geometric proof of this fact is trivial);

2) PAC is the most shielded area of the Farside, with an expected attenuation of man-made RFI ranging from 15 to 100 dB or higher;

3) PAC does not overlap with other areas of interest to human activity except for a minor common area with the Aitken Basin, the southern depression supposed to have been created 3.8 billion years ago during the 'big wham' between the Earth and the Moon.

Where to locate our radio astronomy and SETI facilities within the vast region of the PAC?
The problem is that this is a rugged region, but about 5◦ south along the 180◦ meridian (at 179 degrees east longitude, 5.5 degrees south latitude) we find the 80 kilometer Daedalus Crater. Daedalus is the most shielded crater of all from Earth-made radio pollution even as we extend our radio interference into space at the Lagrange points (and again, assuming we declare L2 off-limits).

What about the L1 and L2 points of the Sun/Earth system? Here we have a problem, because there are already plans for placing satellites there (the original plan for NASA's Space Inteferometry Mission was to place it at the Sun-Earth L2 point, for example). Maccone's thoughts on this: This radio pollution of the Moon Farside by scientific satellites located at the Lagrangian Points L1 and L2 of the Sun-Earth system is, unfortunately, unavoidable. We can only hope that telecom satellites will never be put there. As for the scientific satellites already there or on the way, the radio frequencies they use are well known and usually narrow band. This should help the Fourier transform of the future spectrum analyzers to be located on the Moon Farside to get rid of these transmissions completely.
Maccone's hope is that the PAC will be approved by the United Nations, in pursuit of which he made his presentation in Vienna. Ultimately, declaring the area comprising the PAC an international land under the protection of the United Nations — or by direct agreement among the governments of the space-faring nations — is the only way we can hope to preserve the central farside from activities that would compromise its unique scientific value.

An urgent matter? You bet. It may seem like a remote future given our current problems, but the time will come when commercial and industrial interests will lead to more and more satellites in orbits much higher than geostationary, with consequent degradation to the farside's 'zone of quiet.' Uncontrolled radio frequency interference is already a serious problem for Earth-based radio astronomy. The farside can be the ideal place for radio astronomy and SETI facilities, but only if we act to protect it.
For more on these issues and the mathematics of working out the best protected area location, see Maccone, "Protected antipode circle

on the Farside of the Moon," *Acta Astronautica* 63 (2008), pp. 110-118.